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Flora and vegetation of the Eastern Goldfields Ranges: Part 4. Highclere Hills

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Abstract

A study of the flora and plant communities of the Highclere Hills (which lie some 25 km NNW of Bullfinch) recorded 242 taxa in the spring of 1996. Of these, 217 taxa were native and 25 were weeds. The flora list includes *Acacia xerophila* var *brevior*, *Stenanthemum newbeyi* and *Tricoryne tuberosa* ms, which represent significant range extensions for these taxa. No endemic taxa were found on the Highclere Hills. Five community types were defined from 45 quadrats spread across the Hills. The distribution of these community types appears to be primarily related to edaphic factors that were largely independent of topographic position. None of the five community types is known from conservation reserves. The vegetation patterning of the Highclere Hills is n t as complex as that found on nearby ranges due to a more subdued topography. There has been widespread impact on the vegetation of the Highclere Hills by mineral exploration and mining and there is an urgent need to improve environmental management of mineral exploration activities.

Keywords: vegetation, flora, Highclere Hills, survey

Introduction

The Highclere Hills are composed primarily of Archaean (2500 - 3700 MY old) mafic and ultramafic rocks (commonly termed greenstones) and small outcrops of Archaean banded ironstones. Greenstone and banded ironstone ranges are one of the common landforms of the Eastern Goldfields and extend from the Highclere Hills in the west to the Roe Hills some 300 km further east and stretch north-south over 800 km. The Highclere Hills lie some 25 km NNW of Bullfinch, forming part of the western-most greenstone belt in this region. Despite the greenstone ranges being heavily exploited for minerals over the past hundred years, a detailed knowledge of the vegetation and flora of the region is still lacking. The aim of this series is to report on detailed floristic studies on individual ranges to address this deficiency (Gibson *et al.* 1997; Gibson & Lyons 1998ab), and this paper reports recent survey work undertaken in the Highclere Hills.

Study Locality

The geology of the study area (Fig 1) has been mapped and described in detail in Jackson 1: 250000 sheet (Chin & Smith 1983) and the geology and landforms have been summarised by Newbey (1985). The major landscape features are controlled by the Archaean granites, which underlie most of the study area and have weathered into gently undulating plains and broad valleys covered by Tertiary soils (< 65 MY old). Trending NNW to SSE are linear bands of Archaean greenstone (mafic and ultramafic lithologies) and banded ironstone formations that were formed from lacustrine deposits of iron oxides and quartz sand. The Highclere Hills are part of the Bullfinch greenstone belt (Chin & Smith 1983). Widespread laterization of the granites and greenstones is believed to have occurred during the Cainozoic (the last 65 MY). The net result is a very subdued landscape given the long period of erosion this area has undergone. The banded ironstone formation in the Bullfinch belt is relatively thin (< 10 m) unlike that of the Koolyanobbing belt (25 km to the east), which can be 100 m thick (Chin & Smith 1983).

The climate of the region is semi-arid mediterranean with warm winters and hot summers. Mean annual rainfall at Bullfinch (25 km SSE) is 296 mm, but seasonal variation is high. The driest year on record was 1940 with 122 mm, and the wettest was 1963 with 618 mm. Most rain falls in winter and is generally associated with frontal activity from May through August. Summer falls (to 100 mm) are highly erratic and result from thunderstorms. Heaviest falls are associated with rain bearing depressions forming from tropical depressions (Newbey 1985; Anon 1988). The closest meteorological station for which temperature data are available is Southern Cross (60 km SE) where mean maximum temperature is highest in January (34.5 °C) with December through March recording mean annual temperatures above 30 °C with the record highest daily temperature of 45.6 °C. Lowest mean minimum temperatures of below 5 °C are recorded in July and August. Lowest daily minimum temperature on record was -3.8 °C.

The Highclere Hills lie in the South Western Interzone close to the border with the Avon botanical region (Wheatbelt; Beard 1990). The interzone is generally dominated by eucalypt woodlands and shrublands on yellow sandplains and marks the transition in vegetation from the species-rich south-west to the more arid communities of the desert regions. Beard (1972) first described the major structural formations of this area that he grouped into vegetation systems. He defined the vegetation of the greenstones and banded ironstones of the Highclere Hills as forming part of the Highclere System. This System

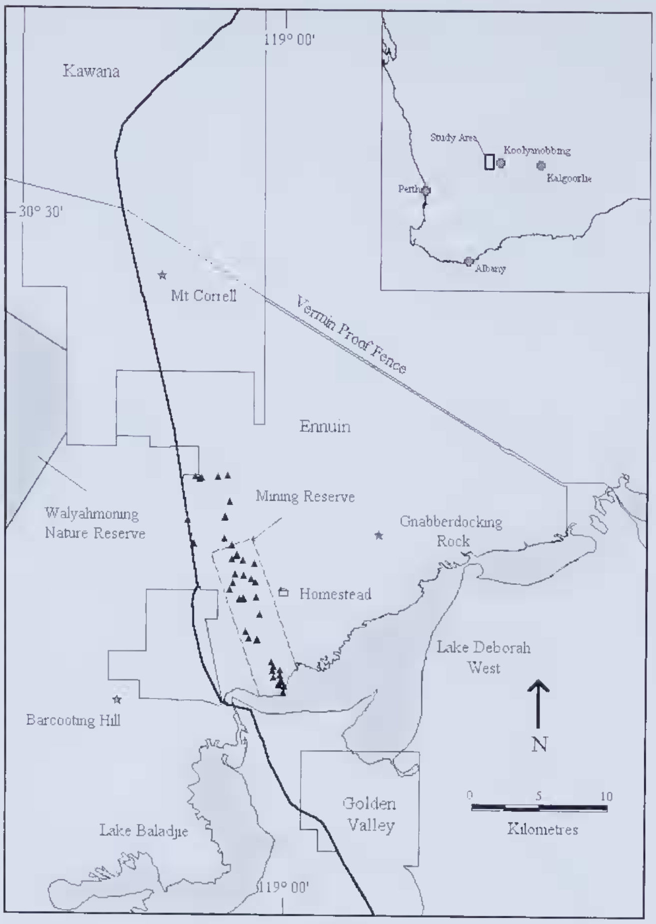

Figure 1. Location of the Highclere Hills study area. Individual quadrats are shown by solid triangles.

also encompasses the greenstone and ironstone areas from near Mt Correll south to Bullfinch. In this system he described the small ironstone outcrops as being covered by thickets of *Acacia quadrimarginea* with a few scattered trees of *Casuarina pauper, Brachychiton gregorii* and *Pittosporum phylliraeoides* with *Dryandra arborea* (which is common on the banded ironstone of the Bungalbin System to the east) being entirely lacking. The hilly country of the greenstone areas were described as being covered by woodlands of *Eucalyptus longicornis* and *E. corrugata* with an understorey of saltbush *Atriplex hymenotheca* and *A. nummularia,* while on the flanks of the hills *Eucalyptus salmonophloia, E. salubris* and *E. loxophleba* woodlands are found.

In the Jackson-Kalgoorlie report of the eastern goldfields regional survey, Newbey & Hnatiuk (1985) described the vegetation of the Highclere Hills under the heading 'Undulating Plain (greenstone)'. They stated that "the Highclere Hills support mainly *Eucalyptus corrugata* Low Woodland on low stony ridges, and *Eucalyptus salmonophloia* Woodland and *E. salubris* Low Woodland on the colluvial flats. Occurring rarely were shrublands of both *Acacia acuminata* and *A.* aff *aneura* on stony rises, and *Eucalyptus longicornis* Low Woodland on the colluvial flats where the soil pH exceed 8.2."

Both Beard's (1972) survey and the later biological survey of the eastern goldfields were undertaken to provide regional overviews. Consequently, the individual ranges were not sampled extensively.

The work reported here covers the section of the Highclere Hill covered by Ennuin Station and the associated mining reserve (Fig 1). Ennuin Station was the first area taken up for grazing in the region with G Lukin and DB Clarkson overlanding sheep from Toodyay in 1871 (Dell 1985) with the station being occupied more or less continuously ever since. Considerable mining and mineral exploration has occurred along the range since the discovery of gold in the Highclere Hills in 1887 (Dell 1985). The grazing rights to the mining reserve that covers part of the Highclere Hills can only be taken up by Ennuin Station (J Gaunlett, Ennuin Station, personal communication).

Methods

Forty-five 20 m x 20 m quadrats were established on the Highclere Hills, its foot slopes and the outwash plain (Fig 1). These quadrats attempted to cover the major geographical, geomorphological and floristic variation found in the study area. Care was taken to locate quadrats in the least disturbed vegetation available in the area being sampled. No attempt was made to undertake detailed sampling of the Tertiary sandplain on the northern boundary of the station nor the adjacent granitic areas (Chin & Smith 1983) although flora lists were compiled from granitic areas abutting the western side of the Hills. Additional records from the Hills were compiled from collections held in the Western Australian Herbarium.

All vascular plants within each quadrat were recorded in October 1996. Data on topographical position, slope, aspect, percentage litter, percentage bare ground, percentage exposed rock, vegetation structure and condition were collected from each quadrat. Topographical position was scored on a subjective five-point scale from ridge tops (1) and upper slopes (2), to midslopes (3), and to lower slopes (4) and valley flats (5). Slope was scored on a one to three scale from flat to steep. Aspect was recorded as one of 16 cardinal directions. Vegetation structure was recorded using Muir's (1977) classification.

All quadrats were permanently marked with four steel fence droppers and their positions determined using a GPS (Trimble, Transpak II). Twenty four soil samples from the upper 10 cm were collected from each quadrat. These were bulked and analyzed for electrical conductivity, pH, total N, total P, percentage sand, silt and clay, exchangeable Ca, exchangeable Mg, exchangeable Na, and exchangeable K (McArthur 1991).

Quadrats were classified according to similarities in species composition of perennial taxa to facilitate comparisons with classifications from other ranges in the area (Gibson *et al.* 1997; Gibson & Lyons 1998ab). The quadrat and species classifications were undertaken used the Czekanowski coefficient and followed by "unweighted pair-group mean average" fusion method (UPGMA; Sneath & Sokal 1973). Semi-strong hybrid (SSH) ordination of the quadrat data was undertaken to show spatial relationships between groups and to elucidate possible environmental correlates with the classification (Belbin

1991). Statistical relationships between quadrat groups for factors such as species richness, soil parameters, slope, and aspect, were tested using Kruskal-Wallis non-parametric analysis of variance (Siegel 1956).

Nomenclature generally follows Green (1985) and current usage at the Western Australian Herbarium. Manuscript names are indicated by "ms". Selected voucher specimens have been lodged in the WA Herbarium.

Results

Flora

A total of 242 taxa (species, subspecies and varieties), representing 217 native and 25 introduced taxa, were recorded from the Highclere Hills. The best-represented families were Asteraceae (48 taxa including 4 weeds), Poaceae (20 taxa including 8 weeds), Myrtaceae (19 taxa), Chenopodiaceae (13 taxa), Mimosaceae (9 taxa), Myoporaceae (8 taxa), and Brassicaceae (8 taxa including 5 weeds). This pattern is typical of the flora of the South Western Interzone (Newbey & Hnatiuk 1985). Good rains were experienced in the winter and early spring of 1996, reflected by the large numbers of annuals and geophytes on the flora list (Appendix 1). The most common genera were *Eucalyptus* (12 taxa), *Acacia* (9 taxa), and *Eremophila* (8 taxa). Grassy weed species were encountered in almost all quadrats, reflecting a long history of grazing.

During the survey new populations of *Stenanthemum newbeyi* were located on small outcrops of banded ironstone and represent a significant range extension. Previously, *S. newbeyi* was believed to be an endemic of the Helena and Aurora Range some 80 km to the north east (Rye 1995).

An unusual species of *Tricoryne* was collected from two populations, one on a banded ironstone ridge and the second on a greenstone ridge. This is the only species in the genus to have a dense many-flowered globular umbel. This taxon will be described as *Tricoryne tuberosa* ms (GJ Keighery, CALM, pers comm).

A significant range extension was also recorded for *Acacia xerophila* var *brevior*. The main area of this taxon's distribution is between Kalgoorlie and Widgiemooltha (Maslin 1999), an outlying population has previously been collected from near South Mt Rankin (MH Simmons 1225), some 60 km SE of the Highclere Hills.

Several areas of granites on the western side to the range were visited during the survey, and six taxa that were not seen on the range were recorded (*Daviesia nematophylla, Eucalyptus capillosa* subsp *capillosa, Eucalyptus celastroides* subsp *celastroides, Frankenia desertorum, Melaleuca haplantha, Wilsonia humilis*).

Vegetation

Only material that could be identified to species level was included in the analysis (*ca* 99% of records). In the 45 quadrats established on the Highclere Hills, 218 taxa were recorded of which 96 were perennial. Twenty nine perennials occurred at only one quadrat. Preliminary analyses showed these singletons had little effect on the community classification and were therefore excluded. As a result the final data set consisted of 67 perennial taxa in 45 quadrats. Species richness ranged from four to 19 taxa per quadrat, with individual taxa recorded from between two and 38 quadrats.

The classification divided the forty five quadrats into two primary groups (Fig 2), the first group which has *Atriplex* spp and *Sclerolaena* spp as common components in the understorey, and the second which generally lacks these taxa (Table 1). Both of these groups can be further subdivided, with a total of five communities being recognized. Within community types 1 and 4, two subgroups could be recognized.

Table 1. Sorted two-way table of the Highclere Hills quadrats showing species occurrence by community type. Quadrats appear as columns, species as rows.

	Community types						
	1a	1b	2	3	4a	4b	5
SPECIES GROUP A							
Abutilon oxycarpum		*		*		*	
Sida atrovirens ms				* *	*	***	
Cheilanthes lasiophylla						* **	
Maireana planifolia		*				*	
Senna artemisioides subsp *filifolia*		* *	*	* *		**	
SPECIES GROUP B							
Eucalyptus loxophleba				**			
Eucalyptus oleosa				*	*		
Hakea recurva				*		*	
Sida spodochroma					* *		
SPECIES GROUP C							
Acacia acuminata				**************	***		
Cheilanthes austrotenuifolia				************* *	**	******	
Casuarina pauper	*			**** *** **	**	*	
Eremophila clarkei				***** * *** **		******	
Eriostemon brucei				**** * ** *		******	
Sida calyxhymenia	*			** ***** ** **	*	***	
Brachychiton gregorii				** ***		****	
Dodonaea inaequifolia				*** * * *	****	*****	

Prostanthera althoferi subsp *althoferi*				** * *** **		*	
Acacia quadrimarginea				****		*** *	*
Acacia tetragonophylla	*	*		*	*****	* ****	
Scaevola spinescens	* *	**	*	*	****	** ***	
Ptilotus obovatus	* ***	* *		**** * ***	*****	** ***	
Solanum lasiophyllum	*			****** ** **	**	* **	
Rhagodia drummondii	**	* *		***	**	* ***	
Acacia ramulosa				* * *			
Eremophila serrulata				* *******			
Dianella revoluta				*** *		***	
Austrostipa aff *trichophylla*				***		*	
Mirbelia microphylla				* *			
SPECIES GROUP D							
Comesperma integerrimum				*	*	* **	
Olearia pimeleoides					*	*	
Stenanthemum newbeyi						* *	
Eremophila alternifolia					* **	*	
Santalum spicatum					***	*	
SPECIES GROUP E							
Allocasuarina campestris				*			*
Amphipogon strictus				*			*
Melaleuca uncinata				** *			
SPECIES GROUP F							
Alyxia buxifolia				*		*	
Centaurea melitensis	*			*			
Pimelea microcephala				*			*
SPECIES GROUP G							
Acacia erinacea	* **	* *			*		
Eremophila oppositifolia	* *	* * *			*	*	
Atriplex nummularia	******	* * **			**		
Atriplex vesicaria	*** **	******* **			*		
Sclerolaena densiflora	** ***	****** ****			**		
Sclerolaena diacantha	******	***********			** *	*	
Maireana trichoptera	*****	******* **	*		*		
Maireana georgei	****	***** *				*	
Eucalyptus longicornis		****** ** *					
Eucalyptus salubris		**** ****					
Enchylaena tomentosa	** *	****** * *			**	*****	
Austrostipa elegantissima	*** *	*** **** *		** *	** **	**** *	
Austrostipa trichophylla	******	*********	*	******* * ** *	*****	******	
Eucalyptus corrugata	** ***	* **	*		**		
Olearia muelleri	****	****	*		**		
Exocarpos aphyllus	* *	* * **			**		
SPECIES GROUP H							
Amyema miquelii		* *					
Eremophila interstans	**	* * *					
Austrostipa nitida		**					
Eucalyptus salmonophloia		** *					
Sclerolaena fusiformis	*	*					
Chenopodium curvispicatum		* * *			*		
Eremophila scoparia	**	* ***				*	
Santalum acuminatum		* *			*		
Dodonaea stenozyga		* *					
Eucalyptus yilgarnensis		* **					
Eucalyptus sheathiana		** *	*				

Community type 1 is typically eucalypt woodland variously dominated by *Eucalyptus longicornis, E. salubris, E. salmonophloia* and /or *E. corrugata* with understoreys dominated by chenopods such as *Atriplex* spp, *Maireana* spp, *Sclerolaena* spp as well as other species in species group G (Table 1). This species group is largely lacking from community types 3, 4 and 5 except for the perennial *Austrostipa* spp and *Enchylaena tomentosa*. Within community type 1, quadrats solely dominated by *Eucalyptus corrugata* can be separated (type 1a) from quadrats dominated by *Eucalyptus longicornis, E. salubris,* and/ or *E. salmonophloia* (type 1b), although *E. corrugata* can co-occur with these species. This division is not correlated with any significant change in the understorey except that *Ptilotus obovatus* appears to be more faithful to type 1a (Table 1).

Community type 2 appears to be a very species poor variant of community type 1. The single quadrat that makes up community type 2 was very species poor (7 taxa) compared to community type 1 (mean 13 taxa/quadrat). It was noted that occasional large open areas occurred in the woodlands of community type 1, which were almost totally devoid of vegetation.

Community type 3 is typically dominated by *Acacia acuminata* with *Casuarina pauper* being a common component. Species group C is generally both faithful and constant to types 3 and 4; however there are clearly different patterns in species occurrences between these types within this species group. There are also obvious differences in species dominance between these types, with almost all quadrats in community type 3 being dominated by an *Acacia acuminata* shrubland. Mean species richness is 11 taxa/quadrat. Both community types show low representation of species group F (except for the *Austrostipa* spp and *Enchylaena tomentosa* as previously mentioned).

Community type 4 is characterized by species such as *Acacia tetragonophylla* and *Scaevola spinescens*. Species group D is almost totally restricted to community type 4. Mean species richness is 15.7 taxa/quadrat. This community type can be subdivided into two subgroups. Type 4b is entirely restricted to ridges of massive banded ironstone and can easily be separated from type 4a by the occurrence of such species as *Eremophila clarkei, Eriostemon brucei, Acacia quadrimarginea* and *Stenanthemum newbeyi*, while community type 4a generally occurs on somewhat deeper soils lower in the landscape.

Community type 5 is represented by a single quadrat located on an eroding lateritic breakaway. This landform was rare in the study area. This quadrat contained few shared perennial taxa (4 only) while a further 10 perennial taxa were recorded only at this quadrat. The quadrat was dominated by *Allocasuarina campestris, Baeckea elderiana* and *Grevillea paradoxa*. A similar community type has previously been encountered on lateritic areas in the Hunt and Mt Manning Ranges some 70–100 km to the north east (Gibson, unpublished data).

Environmental Correlates

Soil and geomorphological parameters

Soil parameters were highly inter-correlated, however altitude, slope and topographic position were not significantly correlated with any soil parameter (Table 2). Percentage sand, silt and clay showed the least intercorrelation with other soil parameters; percentage sand was not correlated with any nutrient while percentage clay was significantly correlated with pH and percentage silt with exchangeable K. This is at variance with results from the Bremer and Parker Ranges where high correlations were found between percentage soils fractions and soil nutrients (Gibson & Lyons 1998a,b).

Community types 2 and 5,which were represented by single quadrats, were excluded from statistical analysis of the environmental differences. There were no significant differences between mean altitude, slope or topographic position occupied by the community types 1, 3 and 4 (Table 3). Within community type 4, one subgroup (4b) generally occupied ridge tops or upper slopes. The major division in the dendrogram between community types 1 and 2 and community types 3, 4 and 5 are also apparent in the soil nutrient data (Table 4). Community type 1 occurred on calcium-rich sites with significantly higher pH, and exchangeable ion than community types 3 and 4. These soils generally show high levels of soil P, similar to community type 4.

Soils from community types 3 and 4 could most easily be differentiated by pH, total P, total N, and exchangeable ions, with community type 3 having lower values, with almost a 50% reduction in terms of total N and P.

Soil from the single quadrat of community type 2 was essentially similar to the means reported for community type 1, consistent with the interpretation that it is a depauperate example of that community type. Community type 5 was represented by a single quadrat from the top of a lateritic breakaway. The soils from this quadrat recorded the lowest pH (6.2) and had very low levels of all soil nutrient compared with all other quadrats. Soils at this quadrat contained a high percentage of sand (90%) compared with values of 66.3 to 74.5% for the other community types.

Ordination results

Ordination of the quadrat data was undertaken to show spatial relationships between groups and to better elucidate possible environmental correlates with the classification. The results of a three-dimensional ordination (stress level 0.16) shows good separation of most of the classificatory groups. The first and second axes separated

Figure 2. Dendrogram of the floristic quadrats from the Highclere Hills showing the five group level classification.

Table 2. Matrix of Spearman rank correlation coefficients between environmental parameters. Only correlations significant at P < 0.01 shown ($r^2 \geq 0.3721$). See methods for soil parameter codes.

	Altitude	Aspect	Ca	Clay	EC	K	Mg	Na	Total N	pH	Total P	Sand	Silt	Slope
Aspect	-	1.000	-	-	-	-	-	-	-	-	-	-	-	-
Ca	-	-	1.000	-	-	-	-	-	-	-	-	-	-	-
Clay	-	-	-	1.000	-	-	-	-	-	-	-	-	-	-
EC	-	-	0.798	-	1.000	-	-	-	-	-	-	-	-	-
K	-	-	0.701	-	0.681	1.000	-	-	-	-	-	-	-	-
Mg	-	-	0.569	-	0.510	0.567	1.000	-	-	-	-	-	-	-
Na	-	-	-	-	0.501	0.505	0.754	1.000	-	-	-	-	-	-
Total N	-	-	0.768	-	0.643	0.469	-	-	1.000	-	-	-	-	-
pH	-	-	0.659	-0.379	0.763	0.694	0.621	-	0.375	1.000	-	-	-	-
Total P	-	-	0.412	-	-	-	-	-	0.719	-	1.000	-	-	-
Sand	-	-	-	-0.754	-	-	-	-	-	-	-	1.000	-	-
Silt	-	-	-	-	-	0.393	-	-	-	-	-	-0.855	1.000	-
Slope	-	-	-	-	-	-	-	-	-	-	-	-	-	1.000
Topography	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 3. Plant community mean values for altitude, topographic position (1-ridge top to 5-valley floor), slope class (1-flat to 3-steep), aspect (16 cardinal directions) and species richness. Differences between means for community types 1, 3 and 4 (in bold) tested using Kruskal-Wallis non-parametric analysis of variance. (ns indicates not significant, ** indicates P < 0.01).

Community type	1	2	3	4	5
Altitude ^{ns}	**381**	370	**403**	**386**	420
Topography ^{ns}	**2.9**	4.0	**2.8**	**2.2**	1.0
Slope ^{ns}	**2.0**	2.0	**2.1**	**2.2**	1.0
Aspect ^{ns}	**4.4**	3.0	**5.1**	**4.0**	0.0
Species richness **	**13.1**	7.0	**11.0**	**15.8**	4.0

Table 4. Plant community mean values for soil parameters. Differences between means for community types 1, 3 and 4 (in bold) tested using Kruskal-Wallis non-parametric analysis of variance. (ns indicates not significant, * indicates P < 0.05, ** indicates P < 0.01, *** indicates P < 0.001, **** indicates P < 0.0001).

Community type	1	2	3	4	5
EC ****	**18.1**	11.0	**3.7**	**10.3**	1.0
pH ****	**8.18**	8.50	**6.63**	**7.11**	6.20
Total N ****	**0.198**	0.128	**0.085**	**0.192**	0.032
Total P ***	**213.3**	107.0	**150.5**	**286.5**	79.0
% Sand ^{ns}	**68.2**	74.5	**66.3**	**69.0**	90.0
% Silt *	**19.1**	17.0	**18.6**	**15.3**	4.5
% Clay *	**12.7**	8.5	**15.1**	**15.8**	5.5
Exchangeable Ca ****	**18.5**	10.5	**6.3**	**11.8**	0.9
Exchangeable Mg ****	**6.04**	2.91	**2.35**	**3.20**	0.26
Exchangeable Na ****	**0.34**	0.06	**0.10**	**0.11**	0.02
Exchangeable K ***	**1.30**	0.64	**0.69**	**0.77**	0.10

community type 5 from all other quadrats, further indicating its very different nature. The first and the third axes show the gradation from community type 1 (bottom left) through community type 4 (center) to community type 3 (top right; Fig 3). The outlying nature of community type 5 is still apparent as is the relationship between the species poor community type 2 to community type 1.

Superimposed on the figure are the best fit linear correlations (r > 0.70) of the environmental parameters measured using principal axis correlation (Belbin 1993). The four most highly correlated soil parameters were pH, exchangeable Ca, conductivity and exchangeable K. All four parameters show gradients in virtually the same direction, consistent with a major nutrient gradient decreasing from the lower left of the figure toward the upper right. Quadrats on banded ironstones (type 4a) form the tight cluster in the center of the figure.

Discussion

The section of the Highclere Hills on Ennuin Station has a rich flora of some 242 taxa and the flora list for the station would be considerably extended if detailed surveys were

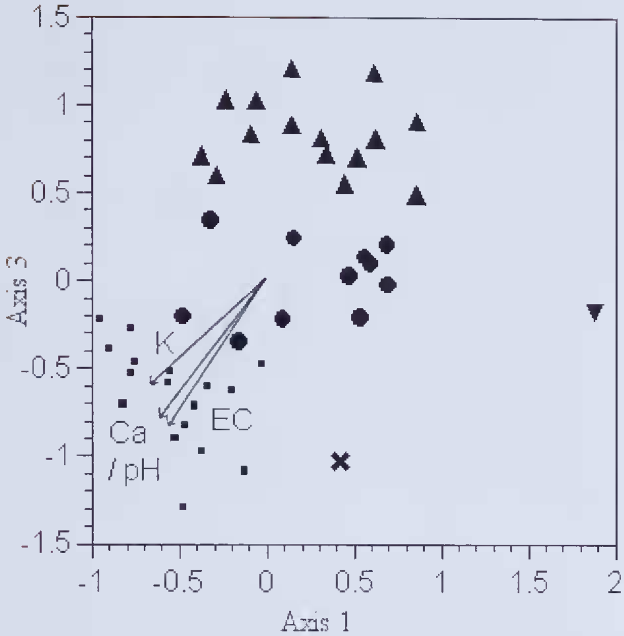

Figure 3. Ordination of Highclere Hill floristic quadrats coded by community type (1 square, 2 cross, 3 triangle, 4 circle, 5 inverted triangle). Arrows show the direction of the best fit linear correlation for the four most significant environmental parameters, exchangable K, exchangable Ca, pH and electrical conductivity (EC).

undertaken of the granitic and sandplain areas. The discovery of two populations of *Stenanthemum newbeyi* represents a significant range extension for the taxon from the Helena and Aurora Range some 80 km to the north east, where it was believed to be endemic to the massive banded ironstones of that range. *Stenanthemum newbeyi* occurred in the same habitat on the Highclere Hills but, as was noted above, this habitat is very much more restricted in the Highclere Hills.

Two populations of *Tricoryne tuberosa* ms were recorded from the range. This species was previously known from two collections from Karroun Hill area (100 km NW of Ennuin). A recent collection of a *Tricoryne* in bud (R Soullier 628) from the Mingenew area may be attributable to this taxon but further survey is required to determine its precise distribution and conservation status.

The collection *Acacia xerophila* var *brevior* from the Highclere Hills and the earlier collection from South Mt Rankin (some 60 km SE) suggests that this taxon may be more widespread along the western most greenstone belt than earlier supposed.

Two species, *Hakea rigida* (= *Hakea* sp (KRN 9589)) and *Leptosema aculeatum* (= *L. chambersii* subsp nov (KRN 9597)), that Newbey & Hnatiuk (1985) highlighted as notable range extensions to the Highclere Hills, were not located during the present survey. *Hakea rigida* is now known to occur in the central wheatbelt and South Western Interzone from Lake Campion north to Wialki and east to area north of Southern Cross (Barker *et al.* 1999). The Highclere Hills population of *L. aculeatum* represents the western extent of this species.

The flora list for the Highclere Hill is somewhat poorer than that recorded for Helena and Aurora Range and similar to that of the Bremer Range and the Parker Range (Table 5). However, the latter two ranges were sampled in a very dry year and numbers of annuals and geophytes would be significantly underestimated (Gibson *et al.* 1997; Gibson & Lyons 1998ab). The smaller flora list for the Highclere Hills (given the abundance of annuals recorded) probably reflects the much more subdued topography of the Hills compared to the other ranges and hence lower level of habitat heterogeneity.

There is some consistency in the biogeographic patterns seen in the diversity of species-rich genera with those reported for the Helena and Aurora Range, located some 80 km to the north-east (Gibson *et al.* 1997). The Hills showed a similar decrease in number of eucalypt and *Melaleuca* spp compared with the more southerly the Bremer and Parker Ranges. However, fewer *Acacia* and *Eremophila* spp were recorded on the Hills than were found on the Helena and Aurora Range. No endemic taxa have been recorded from this section of the Highclere Hills.

The effects of this subdued habitat are also seen in the vegetation classification. Both Beard (1972) and Newbey & Hnatiuk (1985) considered that the low stony rises of the Highclere Hills were covered with *Eucalyptus corrugata* and/or *E. longicornis* woodlands with chenopod understoreys, with the associated colluvial flats being dominated by *Eucalyptus salmonophloia* and *E. salubris* woodlands. There is little evidence in our data of this topographic segregation on the Hills, with distribution being highly correlated with edaphic factors (Table 4). For example, localized areas of deeper calcareous soils allow *E. salubris* and *E. salmonophloia* to develop over most

Table 5. Comparison of the floras of the Highclere Hills, the Helena and Aurora Range, the Bremer Range and the Parker Range. Note that data from Bremer and Parker Ranges were collect in a dry year and underestimate the annual floras.

	Highclere Hills	Helena & Aurora Range	Bremer Range	Parker Range
Flora	242	324	267	254
Weeds	25	21	8	10
Endemic taxa	-	4	3	5
Taxa - first collections	-	1	2	2
Eucalyptus spp	12	19	30	29
Acacia spp	9	17	17	20
Eremophila spp	8	14	11	7
Melaleuca spp	2	5	19	14

of the landscape. While it is possible to split the woodlands into those dominated by *E. corrugata* (type 1a) and those dominated by *E. salubris*/*E. salmonophloia* (type 1b) there is little evidence of any significant change in the understorey species between these subtypes (Table 1). The Highclere Hills has fewer eucalypt-dominated communities than the other three ranges for which comparable survey work is available (Gibson *et al.* 1997; Gibson & Lyons 1998ab).

Anand *et al.* (1997) showed high correlation between calcretes and erosional regimes of greenstone lithologies. Within the Highclere Hills both calcareous and acid soils were found developed on the erosional regimes of greenstone lithologies. The highly calcareous soils (mean pH 8.2-8.5) were dominated by community types 1 and 2, while the more acid soils (mean pH 6.6) developed on the same lithology were dominated by community type 3 and to a lesser degree by community type 4a.

Newbey & Hnatiuk (1985) describe shrublands of both *Acacia acuminata* and *A.* aff *aneura* rarely occurring on stony rises. In fact these *Acacia* shrublands (type 3) are one of the more widespread community types on the Ennuin section of the Highclere Hills. Indeed much of the eastern slopes are dominated by this community type. Other *Acacia* shrublands (community type 4a) are also widely distributed on the Hills.

The community of the massive ironstones (type 4b) is fundamentally different from those recorded from the Helena and Aurora Range. The most obvious components of that community (*Dryandra arborea* and *Calycopeplus paucifolius*) appear to be absent from the Highclere Hills. The areas of massive banded ironstone habitat on Ennuin Station are very small and fragmented. The soils of community type 4, although generally thin (<10 cm depth), were near neutral and had similar total P levels to community type 1.

The lateritic community (type 5) was very restricted on Ennuin but is similar in species composition to similar landforms in the Hunt Range and Mt Manning Range (Gibson, unpublished data). Laterization was widespread during the Tertiary and similar laterite communities are widespread in the goldfields ranges.

Beard (1972) classified all of the greenstone and banded ironstone areas of the Highclere Hills into the Highclere vegetation System, extending from north of Mt Correll to just south of Bullfinch. Ennuin Station occupies the middle third of this band. None of this area is covered by any existing conservation reserve and most of the Hills are in a mining reserve.

The Highclere Hills have had a long history of grazing. This is reflected in the vegetation by a high frequency of annual grasses in the 45 quadrats established. While the number of annual grasses is similar to that found on the Helena and Aurora Range they are much more widespread. As quadrats were established in the vegetation in the best condition no detailed analysis of grazing impacts is possible from our dataset. It was noted however, that significant invasion of the introduced *Centaurea melitensis* (Malta thistle or Maltese cockspur) had occurred along some tracks, around old sheep camps and in areas disturbed by mining. This thistle is a native of the Mediterranean region, Asia and Africa, and is a widespread weed in south-west Western Australia. There is also a significant population of *Carrichtera annua* (Ward's weed) around the homestead and yards.

Mineral exploration and mining have had significant local impacts along the Highclere Hills. As with most exploration and mining in the goldfields ranges, there has been little effort to minimize impacts or rehabilitate areas once exploration or mining have ceased. Uncapped drill holes, open costines, abandoned drilling infrastructure, bagged drill hole material and piles of rock cores were common, especially on the northern section of Ennuin. There is an urgent need for stricter environmental conditions to be placed on exploration and mining leases and for more detailed monitoring of these activities.

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Appendix

Flora list for the Highclere Hills (ms denotes a manuscript name, * indicates a weed).

Adiantaceae
Cheilanthes austrotenuifolia
Cheilanthes lasiophylla

Aizoaceae
Gunniopsis rubra
* *Mesembryanthemum nodiflorum*
Tetragonia moorei

Amaranthaceae
Ptilotus carlsonii
Ptilotus divaricatus
Ptilotus exaltatus
Ptilotus gaudichaudii
Ptilotus holosericeus
Ptilotus obovatus
Ptilotus spathulatus

Anthericaceae
Arthropodium dyeri
Caesia occidentalis
Thysanotus patersonii
Thysanotus speckii
Tricoryne tuberosa ms

Apiaceae
Daucus glochidiatus
Hydrocotyle rugulosa
Trachymene cyanopetala
Trachymene ornata
Trachymene pilosa
Uldinia ceratocarpa

Apocynaceae
Alyxia buxifolia

Asclepiadaceae
Rhyncharrhena linearis

Asteraceae
Actinobole uliginosum
Angianthus milnei
Asteridea athrixioides
Blennospora drummondii
Brachyscome ciliaris
Brachyscome ciliocarpa
Calotis hispidula
* *Centaurea melitensis*
Cephalipterum drummondii
Chrysocephalum semicalvum
Erymophyllum ramosum subsp *ramosum*
Gilberta tenuifolia
Gilruthia osbornei
Gnephosis tenuissima
Hyalosperma cotula
Hyalosperma demissum
Hyalosperma glutinosum subsp *glutinosum*
Hyalosperma zacchaeus
* *Hypochaeris glabra*
Isoetopsis graminifolia
Lawrencella rosea
Leucochrysum fitzgibbonii
Millotia myosotidifolia
Millotia tenuifolia
Olearia muelleri
Olearia pimeleoides
Podolepis canescens
Podolepis capillaris
Podolepis lessonii
Podotheca angustifolia
Podotheca gnaphalioides
Pogonolepis stricta
Rhodanthe chlorocephala subsp *rosea*
Rhodanthe haigii
Rhodanthe laevis
Rhodanthe manglesii
Rhodanthe oppositifolia
Rhodanthe polycephala
Rhodanthe rubella
Schoeniacassiniana
Senecio glossanthus
* *Sonchus oleraceus*
Streptoglossa liatroides
Trichanthodium skirrophorum
* *Urospermum picroides*
Vittadinia humerata
Waitzia acuminata
Waitzia citrina

Boraginaceae
Plagiobothrys plurisepalus

Brassicaceae
* *Brassica tournefortii*
* *Carrichtera annua*
* *Heliophila pusilla*
Lepidium rotundum
* *Sisymbrium irio*
* *Sisymbrium runcinatum*
Stenopetalum filifolium
Stenopetalum lineare

Caesalpiniaceae
Senna artemisioides subsp *filifolia*
Senna cardiosperma subsp *cardiosperma*

Campanulaceae
Wahlenbergia preissii
Wahlenbergia tumidifructa

Caryophyllaceae
* *Cerastium glomeratum*
* *Silene gallica*
Stellaria filiformis

Casuarinaceae
Allocasuarina acutivalvis
Allocasuarina campestris
Casuarina pauper

Chenopodiaceae
Atriplex nummularia
Atriplex vesicaria
Chenopodium curvispicatum
Enchylaena tomentosa
Maireana carnosa
Maireana georgei
Maireana planifolia
Maireana trichoptera
Maireana triptera
Rhagodia drummondii
Sclerolaena densiflora
Sclerolaena diacantha
Sclerolaena fusiformis

Colchicaceae
Wurmbea murchisoniana

Convolvulaceae
Wilsonia humilis

Crassulaceae
Crassula colorata

Cuscutaceae
* *Cuscuta epithymum*

Cyperaceae
Schoenus nanus

Dilleniaceae
Hibbertia glomerosa

Droseraceae
Drosera menziesii

Epacridaceae
Leucopogon breviflorus

Euphorbiaceae
Euphorbia drummondii
Poranthera microphylla

Frankeniaceae
Frankenia desertorum

Geraniaceae
* *Erodium cicutarium*
Erodium cygnorum

Goodeniaceae
Brunonia australis
Goodenia berardiana
Goodenia krauseana
Goodenia mimuloides
Goodenia occidentalis
Scaevola spinescens
Velleia rosea

Haloragaceae
Gonocarpus nodulosus
Haloragis gossei

Lamiaceae
Hemigenia brachyphylla
Prostanthera althoferi subsp *althoferi*
Prostanthera incurvata

Lobeliaceae
Lobelia heterophylla
Lobelia winfridae

Loganiaceae
Phyllangium paradoxum

Loranthaceae
Amyema benthamii
Amyema gibberula var *tatei*
Amyema miquelii

Malvaceae
Abutilon oxycarpum
Alyogyne hakeifolia
Lawrencia repens
Sida atrovirens ms
Sida calyxhymenia
Sida spodochroma

Mimosaceae
Acacia acuminata
Acacia assimilis subsp *assimilis*
Acacia coolgardiensis subsp *effusa*
Acacia erinacea
Acacia nyssophylla
Acacia quadrimarginea
Acacia ramulosa
Acacia tetragonophylla
Acacia xerophila var *brevior*

Myoporaceae
Eremophila alternifolia
Eremophila clarkei
Eremophila gibbosa
Eremophila interstans
Eremophila oppositifolia
Eremophila oppositifolia var *angustifolia* ms
Eremophila scoparia
Eremophila serrulata

Myrtaceae
Baeckea elderiana
Calothamnus gilesii
Chamelaucium pauciflorum subsp *thryptomenioides* ms
Eucalyptus capillosa subsp *capillosa*
Eucalyptus celastroides subsp *celastroides*
Eucalyptus corrugata
Eucalyptus ewartiana
Eucalyptus longicornis
Eucalyptus loxophleba
Eucalyptus oleosa
Eucalyptus salmonophloia
Eucalyptus salubris
Eucalyptus sheathiana
Eucalyptus transcontinentalis
Eucalyptus yilgarnensis
Euryomyrtus maidenii ms
Malleostemon tuberculatus
Melaleuca haplantha
Melaleuca uncinata

Ophioglossaceae
Ophioglossum sp (Cranfield & Spencer 7734)

Orchidaceae
Caladenia roei
Cyanicula amplexans
Microtis media
Pterostylis picta
Pterostylis spathulata
Thelymitra aff *macrophyllum*

Papilionaceae
Daviesia nematophylla
* *Medicago laciniata*
* *Medicago minima*
Mirbelia microphylla
Swainsona kingii

Phormiaceae
Dianella revoluta

Plantaginaceae
Plantago aff *hispidula* (NG & ML 1732)

Poaceae
* *Aira caryophyllea*
Amphibromus nervosus
Amphipogon strictus
Aristida holathera
Austrodanthonia caespitosa
Austrostipa elegantissima
Austrostipa nitida
Austrostipa scabra
Austrostipa trichophylla
Austrostipa aff *trichophylla*
Bromus arenarius
* *Bromus diandrus*
* *Bromus rubens*
Cymbopogon sp (Newbey 9550)
Elymus scaber
* *Hordeum leporinum*
Monachather paradoxus
* *Pentaschistis airoides*
* *Rostraria pumila*
* *Schismus barbatus*
* *Vulpia myuros*

Polygalaceae
Comesperma integerrimum

Portulacaceae
Calandrinia corrigioloides
Calandrinia eremaea

Primulaceae
* *Anagallis arvensis*

Proteaceae
Grevillea obliquistigma
Grevillea paradoxa
Grevillea sarissa subsp *sarissa*
Hakea preissii
Hakea recurva

Rhamnaceae
Stenanthemum newbeyi
Stenanthemum stipulosum
Trymalium myrtillus

Rutaceae
Eriostemon brucei

Santalaceae
Exocarpos aphyllus
Santalum acuminatum
Santalum spicatum

Sapindaceae
Dodonaea divaricata
Dodonaea inaequifolia
Dodonaea stenozyga

Solanaceae
Nicotiana occidentalis
Solanum cleistogamum
Solanum lasiophyllum
Solanum simile

Sterculiaceae
Brachychiton gregorii
Rulingia sp (Newbey 9588)

Surianaceae
Stylobasium spathulatum

Thymelaeaceae
Pimelea microcephala

Urticaceae
Parietaria debilis

Violaceae
Hybanthus floribundus subsp *floribundus*

Zygophyllaceae
Zygophyllum eremaeum
Zygophyllum ovatum